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# THE PROBLEM OF HUMAN STATOKINETIC STABILITY IN AVIATION AND SPACE MEDICINE

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16. Abstract

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Statokinetic stability means the capacity of the organism to maintain stable working capacity, spatial orientation, and the function of equilibrium during the organism's exposure to factors that appear during passive and active movements in space (accelerations, optokinetic stimuli).

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THE PROBLEM OF HUMAN STATOKINETIC STABILITY
IN AVIATION AND SPACE MEDICINE

V. I. Kopanev

ABSTRACT. The article provides a scientific basis for statokinetic stability, reveals the character of its changes under conditions of aviation and space flight, and identifies ways of preventing statokinetic disorders.

Statokinetic stability means the capacity of the organism to maintain stable working capacity, spatial orientation, and the function of equilibrium during the organism's exposure to factors that appear during passive and active movements in space (accelerations, optokinetic stimuli).

Statokinetic stability decreases under conditions of hypodynamia, high temperature, weightlessness, and during the action of optokinetic stimuli. It depends upon the age (resistance increases with age) and sex of subjects (in the age range of 15 - 20 years, the stability of young men is higher than that of young women). All forms of physical exercises, particularly figure skating, gymnastics, and swimming provide an increase in statokinetic stability.

One of the consequences of exposing the human organism to /476* the combination of factors that appear in flight is the development in flight personnel (cosmonauts) and passengers of motion sickness. Many years of studying this problem on the part of Soviet and foreign investigators (Trusevich, 1887; Pypin, 1888; Dotten, 1893; Voyachek, 1908, 1927, 1946, 1967; Khilov, 1933,

*Numbers in margin indicate pagination of original foreign text.

1934, 1969; Kulikovskiy, 1939; Zyuzin, 1938; Popov, 1939; Vozhzhova, 1946; Vozhzhova, Okunev, 1964; Boriskin, 1954; Syabro, 1954; Rassvetayev, 1958; Okunev, 1958; Kopanev, 1961; Kurashvili, 1967; Pestov, 1964; Vartbaronov, 1965; Barnatskiy, 1965; Komendantov, 1965; Yuganov, 1965; Nikol'skaya, 1966; Kompanets, 1968; Dmitriyev, 1969; Zabutyy, 1970; Kozhukhar', 1970; Lopukhin, 1970; Onufrash, 1970; Pomogaylo, 1970; Barani, 1911; Quix, 1932; Spiegel, 1926; Sjaberg, 1929; Bard, 1948; McMullen, 1955; Graybiel, 1968, 1971, and others) have shown that the basic cause of motion sickness is movement of the body in space, and that pronounced sensory motor and vegetative changes are characteristic of motion sickness. The investigations noted the significance of the functional condition of the vestibular analysor in the genesis of motion sickness, and on the basis of this, the "otolith" theory of motion sickness was developed (Voyachek, 1908, 1927), as were methods of vestibular selection of control personnel, including pilots (cosmonauts), and methods of increasing human resistance to vestibular stimuli (Khilov, 1933, 1934, 1969; Kulikovskiy, 1939; Popov, 1939; Bazarov, 1964, 1970; Lopukhin, 1970; Strelets, 1972, and others).

Notwithstanding the effectiveness of all these measures in the medical support of flights, even today cases of motion sickness of both passengers and flight personnel are observed although to a lesser extent. The results of estimating vestibular stability have not always insured reliable predictions of human conditions under the action of flight factors. The pressing nature of the problem of selection has become even more obvious with man's penetration into space, when the "space" form of motion sickness developed among persons with a known high level of vestibular stability (Gazenko, 1962; Komendantov, Kopanev, 1962; Sisakyan, 1965; Sisakyan, Yazdovskiy, 1962, 1964; Lansberg, 1958; Berry, 1971, 1973; and others).

Considering the above, investigations on further improving methods of selection based on consideration of the physiological mechanisms of motion sickness have continued in many laboratories. The accustomed arsenal of methods of vestibular selection has begun to be expanded by including pharmacological tests, studying the interaction of the analysors, and considering the physiological reactions of different systems of the organism. An example of the practical realization of this new trend was adopting a test device mounted on an unstable support and an optokinetic drum in which the cosmonauts were subjected to a number of statokinetic stimuli in addition to vestibular stimuli. These were made a part of the system of medical and biological investigations and training of cosmonauts (Sisakyan, Yazdovskiy, 1962, 1964; Markaryan, 1970; and others). The statokinetic stimuli are mechanical forces that cause movement of the body in space and accompany physical phenomena (optokinetic stimuli, alternating changes in barometric pressure, etc.).

Considering the physiological mechanisms allowed the investigators to provide a more extensive estimation of human vestibular stability — not only to determine it, but also the capacity to withstand the combined effect of factors that act on man during movement in space, etc., i.e., to estimate statokinetic stability. The necessity of its investigation was first pointed out by N. N. Lozanov (1938). He defined statokinetic stability as "... the capacity of the organism to withstand all possible passive statokinetic stimuli, i.e., linear and circular accelerations, decelerations, jolts ..." (page 86), and noted that many afferent systems play a role in the genesis of the vestibular reactions. This concept evolved from the basic propositions of the "otolith" theory of motion sickness. G. L. Komendantov (1959, 1966) expanded concepts of statokinetic stability, intorducing the principle of functional systematics in the functioning of the analysors (Orbeli, 1938; Anokhin, 1968; and others).

The physiological basis of the afferent branch of statokinetic stability is a functional system of analysors that reflect space (vestibular, optic, interoceptive, skin-mechanical and motor analysors); the efferent branch is the motor component of the equilibrium function (systems of the structures of the second signal system, the conditioned reflexes and locomotion). The regulating (unconditioned and conditioned), static and statokinetic (posture, righting and compensatory) reflexes are included here with the corresponding sensory, motor and vegetative components. Besides the combined function of the analysor systems, ensuring perception of space and the equilibrium function, in the central branch a doubtlessly important element is the coordinating role of the cerebral cortex, the reticular formation and the other subcortical formations (Komendantov, Kopanev, 1963; Komendantov, et al., 1966, 1969, 1972).

Today, statokinetic stability means the capacity of man to maintain stable working capacity, spatial orientation and equilibrium function, and to ensure optimum regulation of physiological functions during exposure to the statokinetic stimuli that appear during active and passive movements in space (Kopanev, 1970).

Determination of statokinetic stability provides a fuller /478
estimate of human resistance to the effect of statokinetic stimuli than vestibular, optic, interoceptive, and other types of stability.

Depending on the mode of movement in space, several partial types of statokinetic stability are distinguished, namely: orthostatic, which is determined during passive or active movements from the horizontal position to the vertical; clinostatic — during movement from the vertical to the horizontal position; static — maintaining a vertical posture (head upward) under the action of the force of gravity, and in this case the velocity is 0; antigravitational — maintaining a vertical posture (head downward) under the action of the force of gravity; kinetic — during the action of different kinds of accelerations (angular, linear, Coriolis, combination), caused by active and passive movements in space; optokinetic — during the action of optokinetic stimuli that appear during active and passive movements in space.

In addition to other types of stability (altitude, temperature, etc.), in its turn, statokinetic stability is a component of general, non-specific stability that determines the condition of the organism during its interaction with the environment, and this ensures stable working capacity of man during his exposure to the most varied extremal environmental conditions.

Particular types of statokinetic stability — in addition to general, non-specific stability — essentially cause all the difficulties, not only for theoretically analyzing the problem, but also for practical realization.

Even today, the problem of statokinetic stability requires further experimental investigations and theoretical generalizations. Specifically, the character of changes in statokinetic stability during man's stay under the unusual conditions of aviation and space flights and during exposure to statokinetic stimuli has not been adequately clarified; reports on the participation of certain analysors in the functional systematics of the analysors that ensure statokinetic stability are limited; methods of increasing statokinetic stability have been studied little and its interaction with other medical-biological problems remains unclear, etc.

The problem of statokinetic stability is of particularly important significance in light of the experience of medical support of aviation and space flights and the occupational selection of transportation workers (Khilov, 1933, 1969; Sergeyev, 1962, 1967; Sisakyan, Yazdovskiy, 1962, 1964; Gazenko, Chernigovskiy, et al., 1964; Babiychuk, 1966, 1972; Karpov, 1966; Nefedov, et al., 1968, 1969, 1972; Gurovskiy, et al., 1967, 1970; Vorob'yev, et al., 1969, 1970a, b; Molchanov, et al., 1970; Vasil'yev, 1971; Isakov, et al., 1971; Rudnyy, 1973; Beckh, 1954, 1959; Gerathewhol, 1956, 1971; Strughold, 1957, 1969; Diringshofen, 1959; Berry, 1967, 1969, 1970, 1971a, b, c, d, 1973; Grandpierre, 1967, 1972; Lomonaco, 1969, 1971, 1972).

The goal of our investigation was to expand concepts concerning statokinetic stability by revealing new aspects of the problem of human resistance to statokinetic stimuli, by verifying the physiological mechanisms, and by providing a basis for practical recommendations for increasing man's statokinetic stability under conditions of aviation and space flight.

An analysis of the state of the problem has made it possible to determine the most important questions requiring immediate scientific solution, namely: a) a study of human statokinetic stability during the action on man of aviation and space flight /479 conditions — relative isolation and hypodynamia, decreased barometric pressure, an altered atmosphere, high temperatures and weightlessness; b) clarifying human resistance to the statokinetic stimuli, varying in physical characteristics, that are most typical for flight conditions, and determining the initial signs of motion sickness; c) investigating the role of the individual analysors, involved in the functional systematics, in ensuring statokinetic stability and clarifying the role of optokinetic stimuli in the origin of motion sickness; and d) establishing ways of preventing statokinetic disorders by the aid of active and passive methods of training.

*Method of research.* Experiments with participants were conducted in the period 1961 — 1970. In order to duplicate the conditions of relative isolation and hypodynamia, as well as decreased barometric pressure, the SBK-48 chamber was used. The experiments in which atmospheric nitrogen was replaced with helium were conducted in a model of the "Vostok" spacecraft; those involving exposure to high temperatures were conducted in a special thermopressure chamber. The investigations under conditions of short-term weightlessness were carried out during parabolic flights aboard specially equipped laboratory aircraft of the TU-104 type. The duration of the period of weightlessness was within intervals of 25 ± 5 — 40 ± 5 seconds. The effect of long-term weightlessness was studied by analyzing the results of spaceflights made during the "Vostok" and "Soyuz" programs.

In order to clarify human resistance to statokinetic factors that differ according to physical characteristics, and to reveal the initial symptoms of motion sickness, the following methodological methods were employed: carrying out a combination of rapid movements of the head for a period of five minutes with a rhythm of 120 movements per minute; rotating with a rhythm of 2 rpm for a period of 2 hours, 6 rpm for a period of 1 hour, 30 rpm for periods of 5 and 30 minutes; rotation on a combination dynamic training device for periods of 5 and 30 minutes; exposure to Coriolis accelerations for a period of 5 minutes. Part of these methods did not require any apparatus, while training devices were used in some cases. A physical analysis of the forces appearing during these methods is provided in the studies of A. I. Yarotskiy (1949, 1951) and V. G. Strelets (1972).

An investigation of the role of the optic and vestibular analysors in the functional system and ensuring statokinetic stability was carried out by the aid of functional loads (closing the eyes, the rotation tests), and also in experiments in which blind persons and deaf and dumb persons participated.

Methods of preventing statokinetic disorders were developed in experiments, with a clarification of the roles of different types of physical training in increasing human resistance to the effect of statokinetic stimuli (examinations of first, second, and third class athletes and masters of sports), a check on the effectiveness of certain methods of swimming (sports: the breast stroke, the crawl, the dolphin stroke, and an experimental method — a style of crawl with rotation about the longitudinal axis of the body) for increasing statokinetic stability, clarification of the effectiveness of physical training of cosmonauts with respect to increasing their statokinetic stability, a check on the possibility of increasing human statokinetic stability under combat conditions by rapid head movements (Yarotskiy, 1949, 1951) and continuous cumulation of Coriolis accelerations (NKUK) (Markaryan, et al., 1966).

In the process of the investigations, as a rule, a number of physiological indices were recorded and certain tests were made. These were arbitrarily divided into several groups: a) vegetative indices: electrocardiogram (ECG), electrocutaneous resistance (ECR), pulse frequency, frequency of respiration, blood pressure; b) indices of the functional condition of the nervous system, including the analysors and the cerebral cortex: the electroencephalogram (EEG), the motor reaction to sonic stimuli (CMR), tremor of the fingers, critical confluence frequency of light flashes (CFLF), phosphene, the tipping test, the counterrotation illusion, post-rotation nystagmus, the "walking in place" test, the graphic "letter" test (Lysakov, Bartanovskiy, 1964); c) indices characterizing the equilibrium function (Strelets, 1972 ) in man while maintaining a vertical, static posture (pedometry) and while walking (ichnography); d) parameters and tests intended to estimate the so-called intellectual (correction table, the graphic "letter" test, the black-red table) and the physical (hand dynamometry) working capacity (Genkin, et al., 1963; Gorbov, Choynova, 1959). /480

Evaluation of statokinetic stability was carried out based on changes in the investigated indices, according to the subjective estimates of the subjects, and according to the character of the physiological reactions during the modified combination of head movements (after Yarotskiy) and during exposure to Coriolis accelerations.

The following methodological methods and devices were developed in the investigation: a) the graphic "letter" test for estimating the functional condition of the vestibular analysor and working capacity of man (Kopanev, 1965); b) together with I. A. Kolosov, a method of analyzing pulse frequency in microintervals of time was employed with division of the "regime" of weightlessness ("dives") into three periods (Kolosov, 1969); c) together with V. Ya. Lopukhin, a method of swimming in the crawl style with rotation about the longitudinal axis of the body was developed (Lopukhin, Kopanev, 1967); d) a method of simulating motion sickness by the aid of the Coriolis accelerations that appear during simultaneous rotations of the human body and periodic inclinations of the trunk at a 60° angle was developed (Kopanev, 1963); e) together with P. G. Shamrov, a method was employed for evaluating the bioelectrical activity of the brain by determining functioning coefficients, interhemispheric and intrahemispheric asymmetry (Kopanev, Shamrov, 1964); f) a method was suggested for estimating human statokinetic stability by measuring fluctuations of a number of physiological indices; pulse frequency, and the ECG parameters; g) together with V. V. Antonov and I. N. Tsyplenkov, a device was developed and built for the purpose of producing slow rotations and remote recording of the physiological indices; an electronic semiconductor metronome was developed and built for producing sonic signals in the dynamic experiments (Antonov, et al., 1967).

Moreover, certain additions were introduced to a number of the methodological methods and devices; the A. I. Yarotskiy test — a method of accomplishing rapid head movements — was carried out by the subjects while sitting rather than while standing (for the purpose of safety); stability of the subjects was not evaluated on the three-point scale, but on the five-point scale (for increasing the accuracy of measurements); the method of recording motions when carrying out the Frukuda "walking in place" test was improved by creating a set of coordinate grids, which made it possible to increase the accuracy of the measurements.

The following training equipment and devices were also used when conducting the experiments: a portable electrically driven Bárány chair, the universal Bárány chair, a combination dynamic training device, and an instrument for investigating the physiological functions (Markaryan, 1970; Strelets, 1972, and others).

As a rule, the results of the investigations were subjected to statistical processing.

## Results of the Investigations /481

Composite data on the volume of the experimental material are provided in Table 1.

As one can see, the analyzed material includes the results of 2,622 experiments (27 series), in which 777 people participated as subjects.

1. The effect of hypodynamia, isolation, decreased barometric pressure, and a helium-oxygen atmosphere on the human organism have been investigated in sufficient detail, both in the Soviet Union and abroad. However, with respect to problems of human statokinetic stability (SKS) under these conditions, there are only a few reports in the studies of Yu. G. Grigor'yev, et al. (1967), I. I. Tikhomirov (1965), T. N. Krupina, et al. (1967), and I. Ya. Yakovleva, et al. (1967, 1972), which indicated certain changes in vestibular-vegetative stability under conditions of hypodynamia.

It was found in our investigations that, under conditions of relative isolation and hypodynamia (up to 60 days), decreased barometric pressure (62 days), and a helium-oxygen atmosphere (10 and 25 days), there was decreased statokinetic stability in the subjects (on the average, by 1 point), which appeared in a deterioration of their feelings and in greater vegetative changes. The latter is illustrated by the data on change in pulse frequency (Table 2).

TABLE 1

GOALS OF THE INVESTIGATION AND THE VOLUME OF EXPERIMENTAL MATERIAL

| No. | Goals of the Investigation | Subjects | Number Series | Experi-ments |
|---|---|---|---|---|
| 1 | A study of human statokinetic stability under conditions of relative isolation, hypodynamia, decreased barometric pressure, and the helium-oxygen atmosphere | 16 | 3 | 16 |
| 2 | A study of human statokinetic stability under exposure to high temperatures | 39 | 3 | 44 |
| 3* | A study of human statokinetic stability under conditions of short-term and long-term weightlessness | 81 | 2 | 1921 |
| 4* | A study of human statokinetic stability during action of statokinetic stimuli that vary in strength | 128 | 7 | 128 |
| 5 | An investigation of the role of optokinetic stimuli in the genesis of statokinetic disorders | 40 | 3 | 40 |
| 6* | A study of the role of the vestibular and optic analysors in maintaining static and dynamic equilibrium | 32 | 1 | 32 |
| 7* | An investigation of human statokinetic stability, depending on the sex and age of the subjects | 111 | 1 | 111 |
| 8* | Developing ways of increasing statokinetic stability by physical training and goal directed training | 297 | 4 | 297 |
| 9** | Methodological experiments | 66 | 3 | 66 |
| | Total | 777 | 27 | 2622 |

*I. A. Kolosov and I. K. Tarasov (#3), S. V. Zhadovskaya (#4, 7), P. K. Shestak, N. I. Popov, Ye. V. Bannov (8), and V. Ya. Lopukhin (6, 8) participated in assembling experimental materials under our scientific supervision.

**Data from examining 33 people are also included in 4 of the table.

TABLE 2

CHANGE IN PULSE FREQUENCY (% IN COMPARISON WITH THE INITIAL LEVEL)

DURING THE YAROTSKIY TEST ACCOMPLISHED BY THE SUBJECTS

UNDER ORDINARY AND UNUSUAL CONDITIONS

| Unusual Conditions | Isolation, hypodynamia | | Isolation, hypodynamia Decreased barometric pressure | | Isolation, hypodynamia Helium-oxygen atmosphere | |
|---|---|---|---|---|---|---|
| Subjects | N-v | Ts-o | Ch-v | A-v | I-v | K-v |
| Pulse frequency, ordinary conditions | +9 — +8 | +3 — +18 | -6 — +4 | +10 — +24 | -2 — +1 | -1 — +4 |
| Pulse frequency, unusual conditions | +12 — +25 | +17 — +31 | -4 — +31 | +8 — +20 | +1 — +12 | +1 — +14 |
| Coefficient t | >2.5 | >2.5 | >2.5 | <2.5 | >2.5 | >2.5 |

The same relationships were observed when analyzing the temporal and amplitude parameters of the ECG, ECR, and other indices both during the test and the period following it. Besides an increase in the vegetative changes, an extension in the illusion of counterrotation and post-rotation nystagmus was noted, as well as the development of inhibition in the cerebral cortex (activation of the alpha-rhythm and the appearance of slow waves). A comparison of the same materials among the series makes it possible to note a certain commonality and equipotentiality of the physiological reactions, notwithstanding the fact that the subjects were under different conditions. Taking the fact into account that all the subjects remained in quarters of limited area for all experiments, the result was a decrease in motor activity (relative hypodynamia), and a decrease in statokinetic stability in the subjects was caused by hypodynamia, under these conditions. The effect of other conditions — relative isolation, decreased barometric pressure, the helium-oxygen atmosphere — was obviously not very significant with respect to statokinetic stability. The difference in the effect of the indicated factors is apparently due to the fact that the qualitative change in afferent impulsation from the receptors of the proprioceptive analysor caused by hypodynamia directly affects the functional systematics of the analysors that ensure statokinetic stability; the other factors (isolation, etc.) act in a mediated fashion, altering the functional condition of the central nervous system, primarily its higher regions (Kakurin, 1968, 1972; Kuznetsov, 1968; and others). The experimental materials indicate the great significance of the regime of motor activity in maintaining statokinetic stability and the necessity of optimizing this regime with respect to changes in external conditions. /482

2. In the studies of S. A. Iosel'son (1963), A. N. Azhayev (1968, 1972), and others, it was noted that, in addition to many functional changes, overheating is frequently accompanied by nausea, vomiting, and other vegetative disorders. As early as the nineteenth century, Russian naval physicians noted that, during voyages in equatorial waters, the number of persons suffering from sick sickness increased, and the sea sickness took a more pronounced form (Trusevich, 1887; Pypin, 1888, and others).

We established that, under conditions of high atmospheric temperatures (40 — 60° for a period of one hour; 80° for a period of 30 minutes), statokinetic stability significantly decreased among subjects (by 2 to 3 points). As a result of this, changes were observed in the vegetative indices, the functional condition of the central nervous system, and in working capacity (Table 3).

The nature of the observed changes was confirmed in most cases during statistical processing, when comparing the results of the examination at the end of the experiment and those of the first examination of the after-effects period with the data prior to exposure. Coefficient t, as a rule, was 2.5 which in /483 P. O. Makarov's opinion (1959), indicates the regular nature of the biological changes.

A decrease in statokinetic stability under exposure to high temperatures also causes a disruption of the functional systematics of the analysors that reflect space. The statokinetic stimuli, acting against a background of overheating of the organism, and consequently, of a functional change in interoception (only predominantly, since certain changes in the other analysors as well are also not excluded), prove to be too strong for most subjects.

TABLE 3

A CHANGE IN CERTAIN INDICES DURING THE SUBJECT'S EXPOSURE TO HIGH TEMPERATURES (MEAN DATA)

| Indices | Temperature in Chamber | Prior to Exposure | At end of Exposure | Subsequently | |
|---|---|---|---|---|---|
| | | | | 0-30 min | 31-60 min |
| Body temperature | +40 | 36.9 | 37.1 | 36.9 | 36.9 |
| | +60 | 36.9 | 37.9 | 37.1 | 36.0 |
| | +80 | 36.8 | 38.9 | 37.2 | 37.0 |
| Pulse frequency (beats per minute) | +40 | 66 | 78 | 70 | 65 |
| | +60 | 67 | 109 | 71 | 69 |
| | +80 | 69 | 135 | 76 | 71 |
| Counterrotation illusion (seconds) | +40 | 28.4 | - | 37.6 | 27.0 |
| | +60 | 26.4 | - | 39.6 | 40.0 |
| | +80 | 22.9 | - | 40.4 | 40.7 |
| Post-rotation nystagmus (seconds) | +40 | 23.7 | - | 31.9 | 29.3 |
| | +60 | 25.1 | - | 38.6 | 31.7 |
| | +80 | 25.3 | - | 37.1 | 34.8 |
| "Endurance" index (in relative units) | +40 | 70.6 | 68.2 | 72.3 | 73.5 |
| | +60 | 67.4 | 61.2 | 65.2 | 66.0 |
| | +80 | 66.2 | 59.8 | 61.3 | 60.0 |
| "Walking in place" test movement value ($cm^2$) | +40 | 1476 | - | 1998 | 1100 |
| | +60 | 896 | - | - | 1622 |
| | +80 | 785 | - | - | 1358 |
| Correction test, number of errors | +40 | 8.3 | 9.1 | 8.5 | 8.0 |
| | +60 | 8.3 | 9.6 | 9.5 | 6.8 |
| | +80 | 7.5 | 11.9 | 9.0 | 6.7 |
| Graphic "letter" test, value of error (degrees) | +40 | 6.8 | 12.0 | 10.6 | 6.1 |
| | +60 | 6.0 | 12.0 | 10.4 | 6.9 |
| | +80 | 6.9 | 8.6 | 12.2 | 7.1 |

A certain role in the genesis of statokinetic disorders is played by a decrease in orthostatic stability, which decreases at high temperatures (Kakurin, 1968; and others). The commonality of the trend in changes in statokinetic and orthostatic stability at high temperatures also makes it possible to hypothesize a unity of mechanisms. This could be explained by a decrease in non-specific resistance of the organism under extreme conditions, which has been mentioned by F. T. Agarkov (1958), N. V. Lazarev (1958), Z. I. Barbashova (1960), and others.

The investigations of F. T. Agarkov (1962) and A. N. Azhayev (1968) have shown that oxygen starvation occurs in subjects during overheating and that inhaling oxygen not only normalizes the physiological reactions, but also the working capacity. N. A. Razsolov (1965) demonstrated that motion sickness worsens during oxygen starvation. Thus, one can hypothesize that the statokinetic disorders in our investigation were also caused by oxygen deficiency and that one of the possible ways of preventing motion sickness is taking measures to prevent oxygen starvation.

3. Serious attention is presently being given to a study /484 of the effect of weightlessness on the human organism. The theoretical prediction of K. E. Tsiolkovskiy (1883, 1911, 1924) and experimental investigations in duplicating weightlessness in fast elevators, aboard aircraft flying a parabolic Kepler curve, and biological experiments performed on animals on artificial Earth satellites have shown that sensory, motor, and vegetative disorders are possible under a condition of weightlessness (Gazenko, et al., 1964, 1966; Parin, et al., 1967, 1968; Yazdovskiy, 1966; Granpierre, 1968). Basic attention has been paid to studying the condition of the vitally important systems of the organism and less to investigations of statokinetic stability.

The goal of our studies was to study human reactions under conditions of short-term weightlessness, to clarify the relationship of these reactions and flight experience, the level of special training, and the degree of human body fixation in the working position, as well as an investigation of human statokinetic reactions during a long period in a state of weightlessness, and to clarify the predictive role of investigations under conditions of short-term weightlessness, applicable to orbital space flights.

An analysis was made of the results of 1910 experimental flights in an aircraft flying along a parabolic curve (70 people with different levels of flight and physical training), during which 7640 "regimes" of weightlessness were produced, and of certain materials of the space flights made by Soviet cosmonauts during the "Vostok" and "Soyuz" programs (Kolosov, 1969). It was found that most of the subjects were observed to have statokinetic disorders during the first introductory flights aboard the aircraft. These had a pronounced form among pilots with a high level of flight training in five persons (16.7% of the group), in nine persons in good physical condition who were not professional flyers (81.9%) and in 23 out of 24 persons (95.8%) who had not undergone special training; the moderately pronounced form was found in 20 (66.6%), 2 (18.1%) and in 1 (4.2%). Statokinetic disorders were absent, beginning with the first "regimes" of weightlessness, in five pilots (16.7% of the group) who had flown over 1500 hours in jet fighter aircraft and who had a great deal of experience under complex weather conditions. Familiarity with weightlessness, on the average, was noted in pilots after the 20th "regime" of weightlessness, after the 33rd to 36th in persons with good physical training, and in the remainder — after the 50th "regime" of weightlessness.

Certain data on the statokinetic reactions of Soviet cosmonauts during short-term and long-term weightlessness are provided in Table 4*(Sisakyan, Yazdovskiy, 1962, 1964; Komendantov, 1965; Vorob'yev, et al., 1969, 1970).

*Table 4 is data of N. I. Popov, I. A. Kolosov, and I. K. Tarasov.

TABLE 4

STATOKINETIC REACTIONS IN COSMONAUTS UNDER CONDITIONS OF SHORT-TERM AND LONG-TERM WEIGHTLESSNESS (According to the data of Sisakyan, Yazdovskiy, 1962, 1964; Gazenko, Gyurdzhian, 1967; Komendantov, et al., 1962; Yuganov, et al., 1965; Vorob'yev, et al., 1969, 1970a, b)

| Last Name, Initials | Estimate of Vestibular Stability before Space Flight, on 5-point Scale | Short-Term Weightlessness (first flights aboard an aircraft flying a Kepler parabola) estimate of SKS on the 5-point scale | Long-Term Weightlessness (space flights) |
|---|---|---|---|
| Gagarin, Yu. A. | 5 | Feels well. No illusions. SKS-5 | Sensory and vegetative reactions are adequate for the unusual conditions. |
| Titov, G. S. | 5 | Feels well. No illusions. Moderately pronounced lability of pulse. SKS-4 | Short-term illusion of flying upside down. Mild symptoms of discomfort. Elevated lability of pulse. Working capacity unchanged. |
| Nikolayev, A. G. | 5 | Feels well. No illusions. SKS-5 | Short-term illusory sensation of the trunk inclined forward during the first space flight, upon transition to the weightless state. Feels well. Vegetative changes adequate for the unusual conditions. |
| Popovich, P. R. | 4 | Feels well. No illusions. SKS-5 | Feels well. Short-term illusion of flying upside down. Lability of pulse. Working capacity unchanged. |
| Bykovskiy, V. F. | 5 | Feels well. No illusions. SKS-5 | Sensory and vegetative reactions adequate for the unusual conditions. |
| Beregovoy, G. T. | 5 | Feels well. No illusions. SKS-5 | Sensory and vegetative reaction adequate for the unusual conditions. |

TABLE 4

(Continued)

| Last Name, Initials | Estimate of Vestibular Stability before Space Flight, on 5-point Scale | Short-Term Weightlessness (first flights aboard an aircraft flying a Kepler parabola) estimate of SKS on the 5-point scale | Long-Term Weightlessness (space flights) |
|---|---|---|---|
| Shatalov, V. A. | 5 | Feels well. No illusions. SKS-5 | Sensory and vegetative reaction adequate for the unusual conditions in flights. |
| Volynov, B. V. | 5 | Feels well. No illusions. SKS-5 | Sensory and vegetative reactions adequate for the unusual conditions. |
| Yeliseyev, A. S. | 5 | Feels well. Moderately pronounced lability of pulse. SKS-5 | Feels well. Mild sensation of blood flowing to the head, disorder of motor coordination. |
| Khrunov, Ye. V. | 5 | Feels well. No illusions. SKS-5 | Sensory and vegetative reactions adequate for the unusual conditions |
| Shonin, G. S. | 5 | Feels well. No illusions. SKS-5 | Sensory and vegetative reactions adequate for the unusual conditions |
| Kubasov, V. N. | 5 | Feels well. Moderately pronounced lability of pulse. SKS-5 | Sensory and vegetative reactions adequate for the unusual conditions. |
| Filipchenko, A. V. | 5 | Feels well. No illusions. SKS-5 | Sensory and vegetative reactions adequate for the unusual conditions |
| Gorbatko, V. V. | 4 | Feels well. No illusions. SKS-5 | Sensory and vegetative reactions adequate for the unusual conditions |
| Sevast'yanov, V. I. | 4 | Feels well. Moderately pronounced lability of pulse. SKS-5 | Feels well. Mild sensation of blood flowing to the head, disorder of motor coordination. |

TABLE 4

(Continued)

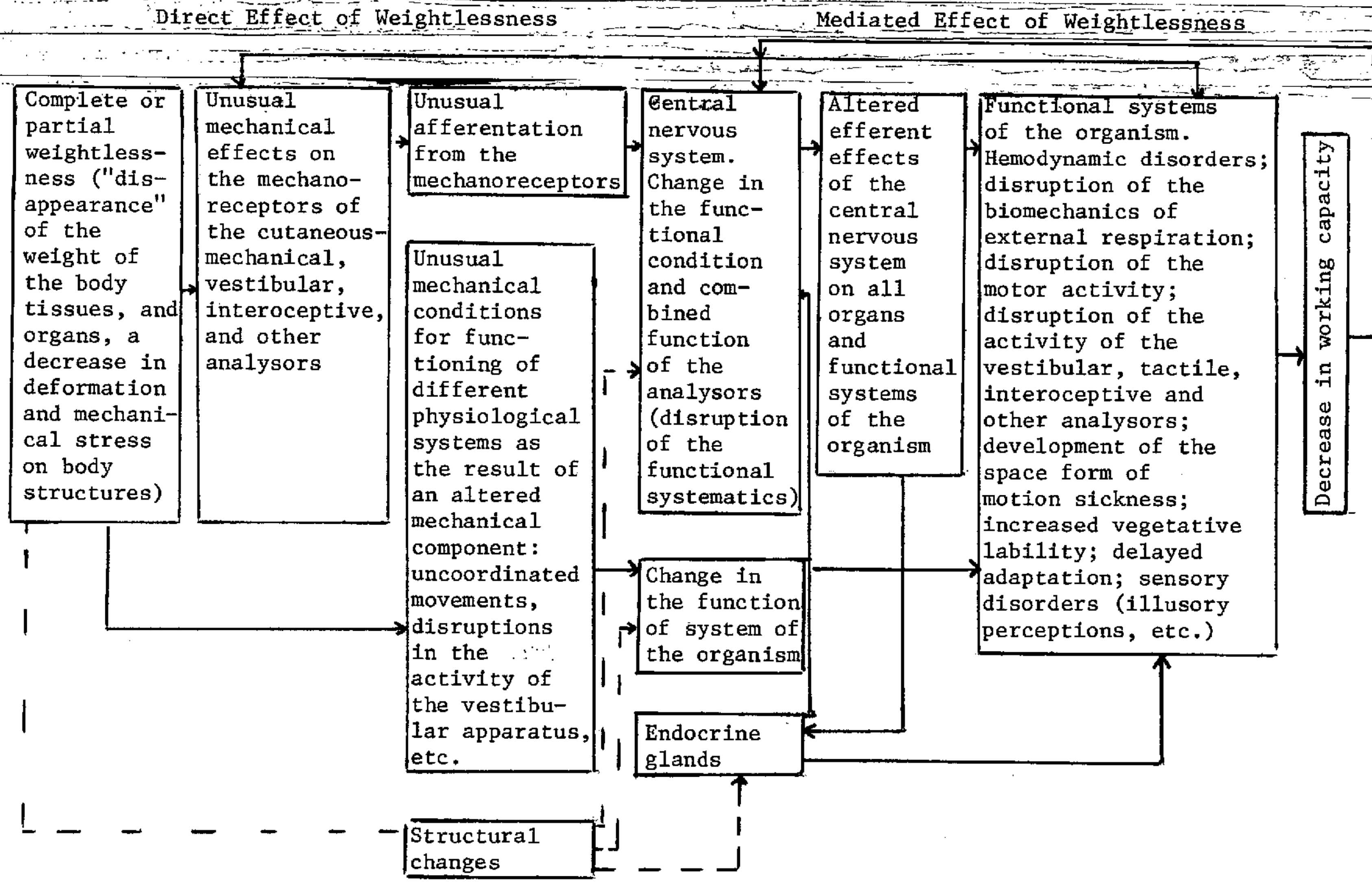
| Last Name, Initials | Estimate of Vestibular Stability before Space Flight, on 5-point Scale | Short-Term Weightlessness (first flights aboard an aircraft flying a Kepler parabola) estimate of SKS on the 5-point scale | Long-Term Weightlessness (space flights) |
|---|---|---|---|
| Lazarev, V. G. | 5 | Feels well. No illusions. SKS-5 | Sensory and vegetative reactions adequate for the unusual conditions |
| Makarov, O. G. | 5 | Feels well. Moderately pronounced vestibulo-vegetative reactions. Lability of pulse. SKS-4 | Feels well. Mild vestibulo-vegetative reactions in flight |
| Tereshkova, V. V. | 5 | Feels well. No illusions. Mild vegetative reactions. SKS-4 | Feels well. No illusions. Lability of pulse. Diminished appetite. Working capacity unchanged. |
| Komarov, V. M. | 4 | Feels well. No illusions. SKS-5 | Sensory and vegetative reactions adequate for the unusual conditions. |
| Feoktistov, K. P. | 4 | Feels well. No illusions. Mild vegetative reactions. SKS-4 | Feels satisfactory. Illusion of flying upside down. Mild dizziness during sharp movements of the head. Sense of discomfort. Lability of pulse, working capacity unchanged. |
| Yegorov, B. B. | 4 | Feels well. No illusions. Mild vegetative reactions. SKS-4 | Feels satisfactory. Illusion of flying upside down. Mild symptoms of discomfort. Working capacity unchanged. |
| Belyayev, P. I. | 5 | Feels well. No illusions. SKS-5 | Sensory and vegetative reactions adequate for unusual conditions |
| Leonov, A. A. | 5 | Feels well. No illusions. SKS-5 | Sensory and vegetative reactions adequate for unusual conditions |

As can be seen, symptoms of motion sickness were observed in certain cosmonauts under conditions of weightlessness. Thence, it follows that the vestibulometric investigations were not adequately predictive in all cases. The data from examining the cosmonauts during aircraft flights along the weightlessness parabola proved more informative. In almost all cases, a relationship was observed between the expression of statokinetic disorders during short-term and long-term weightlessness, which makes it possible to view aircraft flights along a parabolic curve as a functional test for estimating statokinetic stability.

The physiological mechanisms of the effect of weightlessness on the human organism and the development of motion sickness are unclear to this day. On the basis of analyzing our own experimental material and the achivements of the scientific schools of V. V. Parin, O. G. Gazenko, A. V. Lebedinskiy, K. L. Khilov, /486
G. L. Komendantov, M. D. Yemel'yanov, Ye. M. Yuganov, Gerathewhol, Bek, Strughold, Graybiel, and others, we developed a line diagram of the effect of the state of weightlessness on the organism (Table 5). Undoubtedly, the diagram cannot be viewed as conclusive; it will be updated and supplemented. As follows from the diagram, the space form of motion sickness is the result of a disruption in the functional systematics of the analysor function. During an analysis of the statokinetic disorders observed under conditions of weightlessness, one should bear in mind the effect of Coriolis accelerations that appear during movement of the head relative to the axis of rotation of the spacecraft cabin (Khilov, 1969). Taking the fact into account that inertia remains a property of moving bodies under conditions of weightlessness, cases of motion sickness are possible as the result of a disruption in the reciprocal relationships between the otolith and cupular receptor formations (Yuganov, 1965; Gorshkov, 1968). One can imagine the conditioned reflexive origin of motion sickness,

TABLE 5

THE EFFECT OF WEIGHTLESSNESS ON THE ORGANISM



but its role has not yet been clearly defined, i.e., it is of differing significance, depending on many circumstances: it can worsen motion sickness or prevent it.

4. Taking the fact into account that motion sickness under conditions predominantly occurred in a mild form, we made an attempt to characterize the initial symptoms of motion sickness clinically and physiologically. For the purpose of simulation, the most typical statokinetic stimuli that were observed during different methods of movement in space were used (by the aid of the human locomotive apparatus, walking while in motion in a vehicle, or while flying in aircraft). These were rotations, movement about the vertical, and their combinations (Coriolis accelerations, and also rapid head movements. The criterion for the development of initial symptoms of motion sickness was /488
the appearance of symptoms of mild queasiness and discomfort in the subjects.

It was found that a number of indices besides the subjective symptoms were quite informative for estimating the initial manifestations of motion sickness and for differentiating them from the ordinary statokinetic reactions. A moderate increase in pulse frequency, a decrease in the critical confluence frequency of light flashes, and skin galvanic resistance, an increase in tremor, in the latent period of the conditioned-motor reaction to sonic signals, and a slight decrease in working capacity were characteristic for the initial symptoms of motion sickness (Table 6).

Somewhat different changes in the physiological indices were observed in certain subjects in conditions of motion sickness; quickening of the pulse, etc. This is apparently explained by the phase nature of the development of motion sickness

TABLE 6

THE TREND IN CHANGES OF CERTAIN INDICES IN SUBJECTS WITH DIFFERENT DEGREES OF STABILITY

(% in comparison with the original level)

| Indices | Statokinetic Stimuli | Subjects: Without signs of motion sickness | Subjects: With initial symptoms of motion sickness |
|---|---|---|---|
| Pulse frequency | 6 rpm | -7 | -16 |
| | 30 rpm | +4 | -8 |
| | Coriolis accelerations | +4 | -18 |
| Critical frequency of merger of light flashes | 6 rpm | - | - |
| | 30 rpm | -4 | -9 |
| | Coriolis accelerations | -6 | -8 |
| Skin galvanic resistance | 6 rpm | -31 | -40 |
| | 30 rpm | -37 | -65 |
| | Coriolis accelerations | -42 | -75 |
| Latent time of conditioned-motor reaction | 6 rpm | +1 | +7 |
| | 30 rpm | +10 | +16 |
| | Coriolis accelerations | +8 | +17 |
| Tremor | 6 rpm | - | - |
| | 30 rpm | +22 | +42 |
| | Coriolis accelerations | +21 | +36 |
| Transmitting capacity of optic analysor | 6 rpm | -2 | -10 |
| | 30 rpm | -3 | -17 |
| | Coriolis accelerations | -12 | -23 |
| Black and red table, counting time | 6 rpm | +6 | +2 |
| | 30 rpm | +4 | +16 |
| | Coriolis accelerations | +2 | +10 |

(Komendantov, Kopanev, 1963, 1970). The phase nature of changes in the indices and in their "fluctuation" (Razsolov, 1965) must be borne in mind when diagnosing motion sickness. The latter can only be successful when evaluating the combination of indices and the trend in their changes.

A study of the initial symptoms of motion sickness is also important from the viewpoint of investigating motion sickness that has a latent course (Shubert, 1937; Kopanev, 1970a, b), for, although both therapeutic and organizational measures are employed with respect to persons with pronounced motion sickness, in case of latent appearance, this is not done in all cases. Moreover, motion sickness is more frequently encountered in the latent form than in the overt, and is most typical for conditions of aviation and space flight (Kopanev, Yuganov, 1972). Consideration of the objective and subjective indices that characterize the initial symptoms of motion sickness also makes it possible clinically to verify the latent form. /489

Simulation of the initial symptoms of motion sickness by the aid of rotation, vertical movements, Coriolis accelerations, and head movements (after Yarotskiy) has shown that, during passive (rotations, etc.), active (head movements), and mixed (Coriolis accelerations) movements, symptoms of a decrease in statokinetic stability are observed in subjects. These changes make it possible to introduce corrections in the determination of statokinetic stability provided by N. N. Lozanov (1938), including a number of active movements in space. During a comparison of all the statokinetic stimuli (rotations, Coriolis accelerations, etc.), their statokinetic "harm" became clear. Coriolis accelerations had the greatest effect, and vertical movements had the least effect. The differences were due to the physical value of mechanical effects and the optokinetic component. The effectiveness of Coriolis accelerations is another indication of the correctness of using them for stimulating the state of motion sickness (Khilov, 1969; Bryanov, 1963; Kopanev, 1963; Razsolov, 1965; Galle, Yemel'yanov, 1967; Kurashvili, 1967; Graybiel, Knepton, 1972).

5. The theoretical research of G. L. Komendantov (1959) advanced the hypothesis that human SKS is provided in the afferent branch of the combined function of a number of analysors: the vestibular, the optic, the interoceptive, the cutaneous-mechanical, and the proprioceptive. In our study, there was an experimental investigation of the significance of the information emanating from the receptors of the optic and vestibular analysors in maintaining SKS. Healthy people (56 people) were used in the investigation, as well as subjects with health defects (6 deaf and dumb people and 10 blind people); the subjects underwent exposure to statokinetic stimuli with their eyes open and closed. The indices characterizing the condition of the vitally important systems of the organism and the function of equilibrium were recorded.

It was successfully found that the intensity of statokinetic reactions was pronounced to a greater degree in the case of the /490 stimuli acting on a man accomplishing visual control (Table 7).

In the experiments in which the subjects did not close their eyes, the after-effects lasted several hours; in the experiments with eyes open, as a rule, all symptoms disappeared over the course of the first hour. In most cases, differences in the character of the physiological reactions were confirmed during statistical processing.

The great statokinetic "harm" of factors including the optokinetic stimuli was also revealed during the analysis of the frequency of cases of motion sickness. If signs of motion sickness were observed in 11% of the subjects with closed eyes during the effect of rotations, in 7% during the Yarotskiy test, and 19% during Coriolis acceleration, with eyes open, the frequency of motion sickness was, respectively, 54%, 17%, and 60%.

TABLE 7

CHANGE IN CERTAIN INDICES (% IN COMPARISON WITH THE ORIGINAL LEVEL) IN SUBJECTS EXPOSED TO STATOKINETIC STIMULI

AVERAGE DATA

| Indices | Eyes | Rotation 3 rpm | Yarotski Test | Coriolis Acceler-ations |
|---|---|---|---|---|
| Finger tremor | open | 123 | 120 | 128 |
| | closed | 111 | 113 | 120 |
| Skin galvanic resistance | open | 62 | 44 | 71 |
| | closed | 95 | 96 | 89 |
| Latent period of conditioned-motor reaction | open | 111 | 118 | 113 |
| | closed | 105 | 108 | 104 |
| Equilibrium function (pedometry) | open | 396 | 162 | 567 |
| | closed | 90 | 125 | 267 |
| Number of errors (red-black table) | open | 178 | 209 | 365 |
| | closed | 123 | 208 | 100 |

The results of these experiments indicate the great role of optokinetic stimuli in the genesis of statokinetic disorders and also make it possible to make practical recommendations on preventing motion sickness. The latter is achieved by limiting the optokinetic stimuli (closing the eyes) or the action of optic stimuli on man (which are fixed relative to him), as the result of which inhibiting factors affect the vegetative reactions (Yemelyanov, 1966; Fomin, 1970). In the experiments in which the equilibrium function was studied, its imperfection was desmonstrated in persons with physical deficiencies (Table 8).

When examining healthy persons or people with physical deficiencies (the blind and the deaf and dumb), the boundaries (approximate) of the fractional particupation of the optic and vestibular analysors in maintaining static and dynamic equilibrium

TABLE 8

CHANGE IN CERTAIN PARAMETERS OF THE EQUILIBRIUM FUNCTION IN HEALTHY PEOPLE AND IN PEOPLE WITH HEALTH DEFECTS

| Subjects | Pedometry (relative units) | | | | Ichnography (degrees) | | | |
|---|---|---|---|---|---|---|---|---|
| | Ordinary Conditions | | After Vestibular | | Ordinary Conditions | | After Vestibular | |
| | EO | EC | EO | EC | EO | EC | EO | EC |
| Healthy people | 1.55 | 2.26 | 1.65 | 3.82 | 0.9 | 4.0 | 2.1 | 5.3 |
| Deaf and dumb | 8.75 | 26.97 | 8.06 | 20.97 | 5.17 | 10.0 | 3.99 | 7.5 |
| Blind | 5.52 | - | 12.4 | - | 4.4 | - | 27.0 | - |

NOTE: EO — eyes open; EC — eyes closed.

were determined. In static equilibrium, the fractional participation of the optic analysor varied from 7 — 18%; the vestibular — from 6 — 29%; and the other analysors — from 52 — 84%. In dynamic equilibrium, the fractional participation was, respectively, 27 — 30, 23 — 34, and 30 — 44%. As could be expected, their participation varied and depended on the type of equilibrium. In static equilibrium, a large role was played by signalization from the vestibular analysor, and in dynamic equilibrium — by information from the optic analysor.

6. There are few reports in the literature on the relationship of human SKS and sex and age. Indirect data are in the studies of P. N. Pypin (1888), V. I. Voyachek (1927, 1946), V. P. Krapiventseva (1954), G. A. Obraztsova (1961), and Ye. Ya. Bondarevskiy (1963, 1964).

We studied statokinetic stability in young men (90 men) and young women (21 women) in the age group 15 — 20 years. It proved that the stability of women in the age group 15 — 20 years was lower (coefficient t was above 2.5) than the statokinetic stability of young men of the same age. The stability /49 of 15 — 20 year-old young men increased with the increase in age; the younger the young man, the lower statokinetic stability, and vice versa. About the same trend was observed in young women. This principle, however, cannot be distributed over all age groups. With old age, the level of statokinetic stability probably decreases as the result of a decrease in motor activity and neuro-hormonal restructuring. The age differences in young men should be taken into account when organizing the work-rest regime of middle school pupils, students in military schools, and young soldiers of the Soviet Army and Navy.

Educators should know that intensive formation of statokinetic stability occurs in the period from 15 — 20 years of age and that failing to take this factor into account can lead to undesirable results.

A relationship was revealed between the level of statokinetic stability and the excitability of the vestibular apparatus. As a rule, in persons with decreased SKS, vestibular excitability increased. There were divergencies of these indices in certain subjects. The lower SKS in young women is explained by psychophysiological characteristics inherent to the female organism and mainly due to decreased motor activity in the process of life. It is known that boys play more lively games than girls. The same is observed in the later periods. One can hypothesize that the relative hypodynamic conditions of females are reinforced hereditarily to a certain extent and predetermine a lower resistance to statokinetic stimuli.

7. In experiments in which problems of increasing human SKS were studied, basic attention was paid to active methods of training, since they are quite effective for preventing fatigue and are more adequate to the work practice of the pilot and cosmonaut. We first determined the most effective forms of physical exercises. After examining 237 people (of these, 215 were first, second, and third class athletes and masters of sports), it was concluded that all types of physical exercise increase human SKS. Athletes occupied with figure skating, diving, playing basketball, soccer, swimming, and gymnastics were most resistant to statokinetic stimuli, while runners, oarsmen, and volleyball players were less resistant (Table 9).

TABLE 9

CERTAIN DATA ON THE STATOKINETIC STABILITY OF ATHLETES

| Group of Subjects | Number of Subjects in Group | Number of Persons Subject to a Five-Minute Exposure | Time of Exposure (in sec) in Persons with Diminished Stability | Time of Exposure (in sec) in the Entire Group Together |
|---|---|---|---|---|
| Control group | 22 | 6 | 90.2 | 147.4 |
| Gymnasts (parallel bar) | 17 | 11 | 71.1 | 219.2 |
| Boxers | 18 | 8 | 138.7 | 210.4 |
| Light athletes | 17 | 6 | 71.6 | 152.2 |
| Oarsmen | 7 | 3 | 93.5 | 182.0 |
| Soccer players | 31 | 16 | 139.2 | 222.2 |
| Volleyball players | 18 | 9 | 98.8 | 199.4 |
| Basketball players | 22 | 12 | 144.4 | 229.3 |
| Waterpolo players | 16 | 9 | 118.4 | 220.0 |
| Gymnasts (other than bars) | 22 | 14 | 110.0 | 230.9 |
| Swimmers | 21 | 14 | 95.5 | 231.8 |
| Divers | 16 | 11 | 200 | 268.7 |
| Figure skaters | 10 | 7 | 113.0 | 243.9 |

This led to practical recommendations for improving the system of physical training of pilots and cosmonauts (Yarotskiy, 1949, 1951; Men'shikov, 1959; Korobkov, 1962, 1969; Korobkov et al., 1968; Dzhamgarov et al., 1963; Brykov, 1965; Stepantsov, et al., 1972). /492

Obviously, they should have recommended to them exercises characteristic for divers, swimmers, and other althletic specialties, while such exercises as long-distance running should be somewhat limited, since the stability of light athletic specialists was lower with respect to a number of indices than in the people not involved in sports.

Two groups were formed to check the effectiveness of swimming in increasing statokinetic stability.

The first group (control — 15 people) studied and then trained in basic swimming methods (crawl, breast stroke, dolphin stroke); the second group (base — 14 people) trained in the crawl style with rotation about the longitudinal axis of the body. The exercises consisted of two periods: the first — study (35 lessons, 2 months); the second — training (50 lessons, 3 months).

During the swimming training, data concerning the high effectiveness of these exercises in increasing statokinetic stability was confirmed. In the sports types of swimming, the increase was pronounced to a lesser extent than when swimming using the crawl style with rotation around the longitudinal axis of the body (Table 10).

As one can see, SKS of the subjects of the control group underwent a maximum increase of 39%, while that of the base group increased by 84%; the achieved level in the first group was lost after three months, while after six months, a tendency toward a certain decrease was noted in the base group.

TABLE 10

SKS LEVEL (% IN COMPARISON WITH THE ORIGINAL LEVEL) OF PERSONS OF THE CONTROL AND BASE GROUPS IN THE TRAINING PROCESS

| Groups of Subjects | Original Data | By the End of Study | By the End of Training | Subsequently | |
|---|---|---|---|---|---|
| | | | | 3 Months Later | 6 Months Later |
| Control | 100 | 139 | 134 | 102 | - |
| Base | 100 | 154 | 180 | 184 | 155 |

The mechanism of increase in SKS during swimming is apparently the following: immersion in water facilitates a change in afferentation from a number of the receptors and creates conditions for the activity of the central nervous system against a new and altered functional background. The aqueous medium makes it possible comparatively easily to change the position of the body in space, as a result of which training of the functional system of analysors occurs.

In the series of experiments in which the problem of increasing the SKS of the cosmonauts during physical training was investigated, it was shown that the existing system of physical training is adequately effective (Surinov, Khlebnikov, 1966; Karpov, 1966).

A physical training cycle three months long ensures that cosmonauts will maintain their SKS level at the original level, and in a number of cases, even exceed it. In persons with a slight decrease in SKS, it is necessary to conduct goal-directed periods of physical training of longer duration. Additionally, the need for further improvement in the system of physically training cosmonauts by including different physical exercises, all methods of swimming, particularly the crawl style with rotation about the longitudinal axis of the body, became clear.

In the last series of experiments, a study was made of increasing human SKS under military conditions by rapid head movements (after Yarotskiy) and by continuous cumulation of Coriolis acceleration (CCCA). Three groups were formed of healthy people: the first — control (10 people); the second — (6 people) trained by the method of rapid head movements; the third group — (10 people) trained by the CCCA method. The periods of training and the subsequent period lasted two months each. Periodically, every 15 days over the course of four months, the subjects were graded according to the CCCA SKS method. /493

It was established that a moderate increase in SKS was observed in persons of the control group. Exposure time to CCCA was increased by 8.4 — 49.5 seconds (by 5.8 — 34.5%); vegetative symptoms began to appear later: paleness, sweating, etc. (Table 11). This is apparently due to repeated exposures to CCCA, mainly to the specific life style of military collectives. Observance of a regime of work, rest, and diet and systematic classes in physical training not only strengthened the physical condition of the military servicemen, but also created conditions for increasing SKS.

In the second and third groups, in which the subjects trained by the aid of rapid head movements or Coriolis accelerations, a more significant increase in resistance to statokinetic factors was noted than among persons of the control group (Table 11). The latter is confirmed with mathematical processing of the materials. The coefficient of regularity of the observed differences was higher than 2.5. In the second group, exposure time in the training period was increased by 25 — 114.4%, and subsequently by 128.1 — 133.6%; in the third group, respectively, by 13 — 45.9 and 40.2 — 45.9%.

TABLE 11

CHANGE IN CERTAIN INDICES AND SUBJECTS IN THE PROCESS OF TRAINING

AVERAGE DATA

| Indices | | Group | Training Period 1 (background investigation) | 3 | 5 | 7 | Subsequently 9 |
|---|---|---|---|---|---|---|---|
| CCCA method, time of appearance of symptoms from the beginning of exposure (sec) | Time of exposure (appearance of nausea) | First | 143.3 | 169.4 | 170.3 | 191.7 | 190.1 |
| | | Second | 242.5 | 378.3 | 520.0 | 553.3 | 565.0 |
| | | Third | 245.0 | 311.0 | 357.0 | 351.1 | 355.5 |
| | Sweating | First | 115.5 | 111.8 | 113.3 | 136.1 | 140.5 |
| | | Second | 196.0 | 278.0 | 453.0 | 383.0 | 352.0 |
| | | Third | 176.5 | 236.5 | 283.0 | 279.4 | 276.7 |
| | Paleness | First | 91.7 | 91.1 | 90.0 | 100.8 | 97.6 |
| | | Second | 181.7 | 244.9 | 330.0 | 289.6 | 284.2 |
| | | Third | 154.5 | 194.5 | 236.0 | 242.2 | 244.4 |
| Counterrotation illusion (sec) | | First | 37.0 | 32.8 | 33.7 | 32.4 | 34.0 |
| | | Second | 38.0 | 34.0 | 31.0 | 26.0 | 30.0 |
| | | Third | 36.1 | 31.9 | 29.2 | 28.9 | 28.8 |
| Post-rotation nystagmus (sec) | | First | 26.8 | 29.7 | 27.9 | 25.2 | 28.7 |
| | | Second | 42.0 | 37.0 | 37.0 | 29.0 | 32.0 |
| | | Third | 42.8 | 33.7 | 31.4 | 32.4 | 33.1 |

NOTE: The first group did not train; the second and third groups trained for two months.

The effectiveness of the training factors attracted particular attention; this pertained to those factors caused by rapidly rotating the head. A more intensive increase in SKS was observed in the third group, in comparison with the first (control), but in comparison with the second, it was pronounced to a lesser degree.

Taking into account the significant effectiveness of the combination of rapid head movements, it is expedient to recommend it for increasing the SKS of flight personnel and cosmonauts. /494
It can be carried out during morning exercises for a period of 5 — 10 minutes. One should approach the use of Coriolis accelerations (CCCA) more cautiously. They can be selectively recommended for those persions in whom statokinetic disorders have been caused by partial inadequacy of the vestibular apparatus. The data obtained on the effectiveness of a combination of rapid head movements coincide with the results of the investigations of A. I. Yarotskiy (1949, 1951), N. K. Men'shikov (1959), and other investigators.

8. Taking the fact into account that cases of increased sensitivity to statokinetic factors are still encountered in the practice of occupational selection of pilots and cosmonauts (Martimonov, 1963; Korostelev, 1966, 1969), an improvement in methods of selection should be continued along the path toward increased knowledge of SKS. In comparison with the vestibular method, determining SKS allows one more fully to estimate human resistance to the entire gamut of mechanical factors. This proposition is in accordance with our experimental material. In experiments performed on a combination dynamic training device, and in other experiments, cases of the development of motion sickness were observed. Investigations of SKS during aircraft flights and when conventional vestibular tests are combined with optokinetic stimuli were more predictive.

The above makes it possible to formulate the basic requirements on medical-specialty methods of estimating the SKS of flight personnel and cosmonauts. They are the following: 1) the basic task of the medical-flight specialty should be predicting flight working capacity, which should determine the character and direction of all methods used for estimating SKS; 2) the system of examination should include a number of methods directed toward estimating the SKS of candidates for flight schools, of flight personnel (cosmonauts) and also of persons on flight duty (cosmonauts) who have any functional deficiencies of the systems that accomplish perception of space and accomplish the function of equilibrium; 3) methods of estimation should be of three types: a) fast methods that are mainly used for examining flight school candidates. An example of such a method is the examination suggested by A. I. Yarotskiy (1949); b) methods of extensive examination which should be used during the periodic scheduled examinations of flight personnel (cosmonauts). An example can be the methods of N. N. Lozanov (1938), I. I. Bryanov (1963), N. A. Razsolov (1965), and others; c) the third group includes methods satisfying the basic requirements for special functional diagnosis; 4) all methods should have an objective quantitative characteristic both in estimating functional loads and with respect to the results of the examination as well as loads corresponding to the conditions encountered in practice. During this process, the expert functional load can be not only equal to the occupational load, but can exceed it by two-fold or more. The latter is necessary for estimating the stability of the studied function of the nervous system, including the systems that accomplish spatial orientation and the equilibrium function. By increasing functional loads, one can also predict the stability of flight working capacity: SKS in flight personnel (cosmonauts) should be evaluated according to the maintenance of spatial orientation, the equilibrium function, and occupational working capacity; the SKS estimate should take into account the optokinetic component of spatial orientation as well as the extralabyrinth factors. It is expedient to express the end result of estimating SKS by an integral value obtained by considering the sensory, vegetative, and motor components of the statokinetic reaction; the equilibrium function, and occupational working capacity.

9. Our investigation posed the following problems for solution: for a more complete study of human SKS applicable to aviation and space flight, its investigation in the presence of other factors (conditions) of flight is necessary; noise, vibration, etc.; investigations of the afferent, efferent, and central elements maintaining the SKS are expedient for studying the physiological mechanisms. Particular attention should be paid to the role of the proprioceptive, cutaneous-mechanical, and interoceptive analysors, the cerebral cortex, the reticular formation, and the other neural formations. It is vital to continue investigations in studying the fractional participation of the analysors in maintaining SKS; investigations are necessary for studying the relationship of human SKS and other conditions such as age (throughout the entire age range), weight, height, and living conditions (regimes of work, rest, and diet); the clinical aspects of the latent form of motion sickness are subject to further verification as are functional load tests for estimating SKS, the criterion of estimating it, and the most informative physiological indices; further investigations to develop the most effective methods of increasing SKS are necessary (by means of goal-directed training, drugs, etc.). /495

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